

NEMO-3

A search for double beta decay

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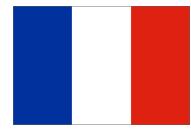
On behalf of the NEMO-3 collaboration

Overview

- **NEMO-3**
 - The collaboration.
 - The detector, sources. event reconstruction.
 - Radon trapping facility (phase 1 and 2 data).
- **Results**
 - Past
 - Latest
- **The future – SuperNEMO**
 - Comparison with NEMO-3.
- **Summary**

NEMO3

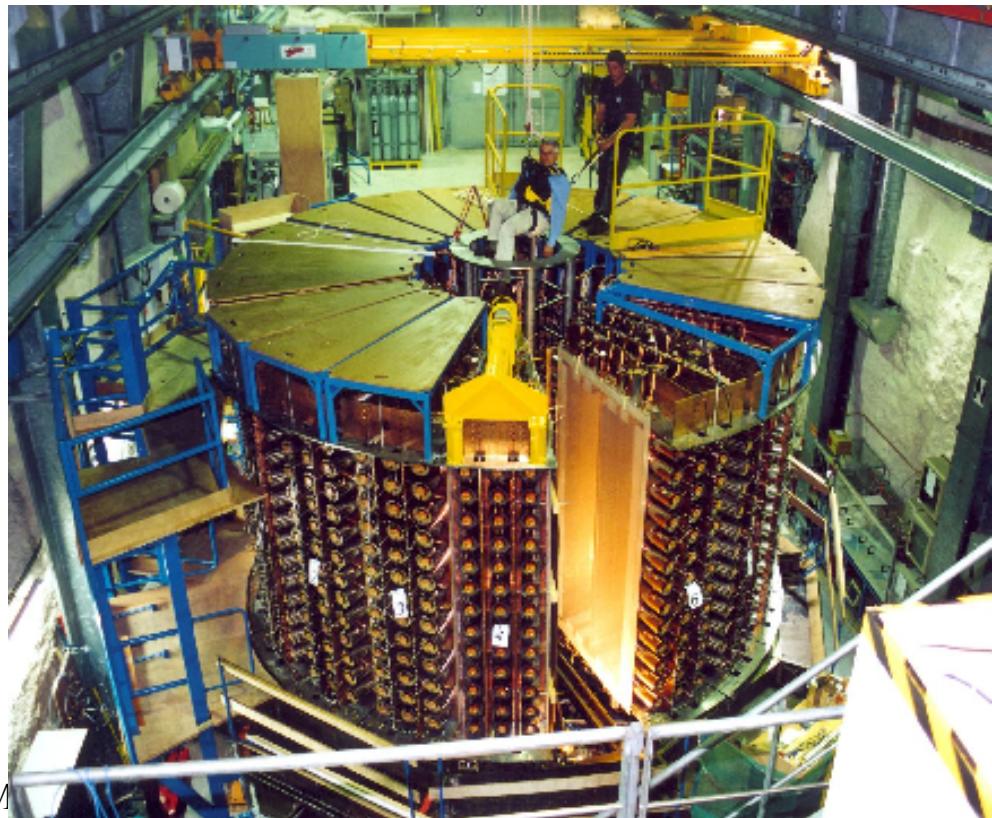
(Neutrino Ettore Majorana Observatory)



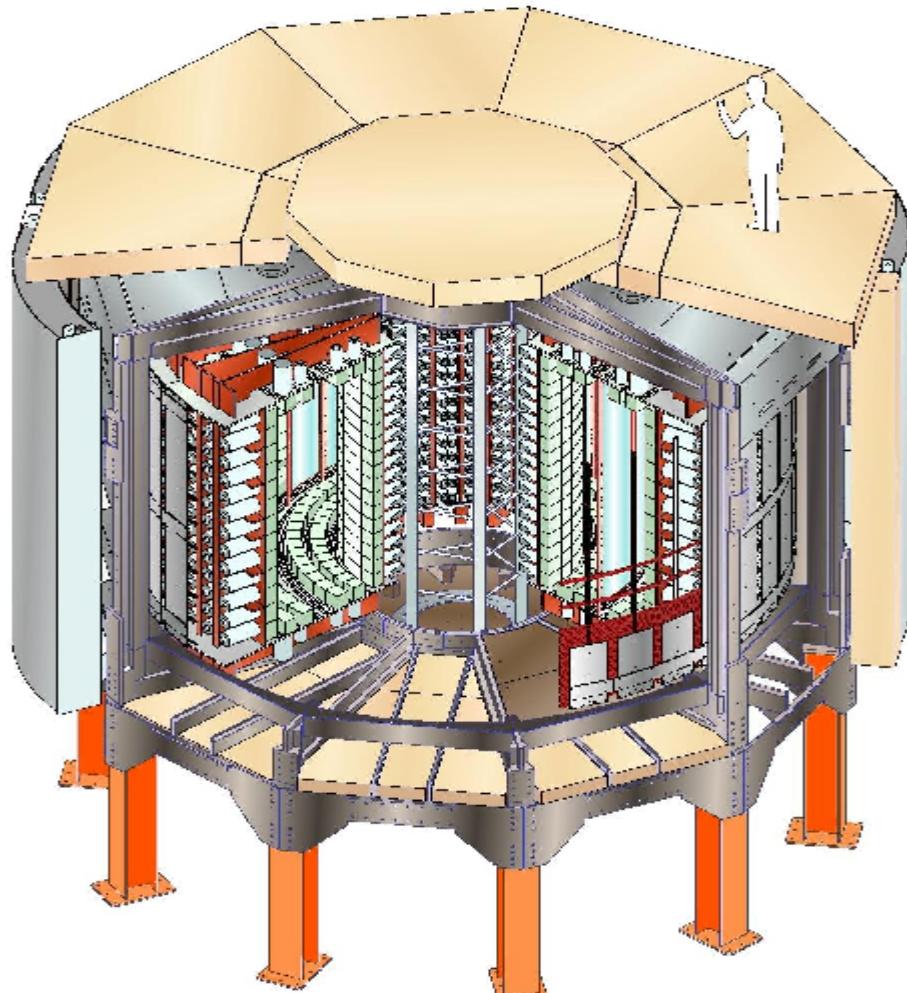
60 physicists, 17 institutions



LS Modane, FR
Tunnel Frejus



Fréjus Underground Laboratory : 4800 m.w.e.



Source: 10 kg of $\beta\beta$ isotopes
cylindrical, $S = 20 \text{ m}^2$, $d \sim 60 \text{ mg/cm}^2$

Tracking detector:
drift wire chamber operating
in Geiger mode (6180 cells)

Gas: He + 4% ethyl alcohol + 1% Ar + 0.1% H₂O

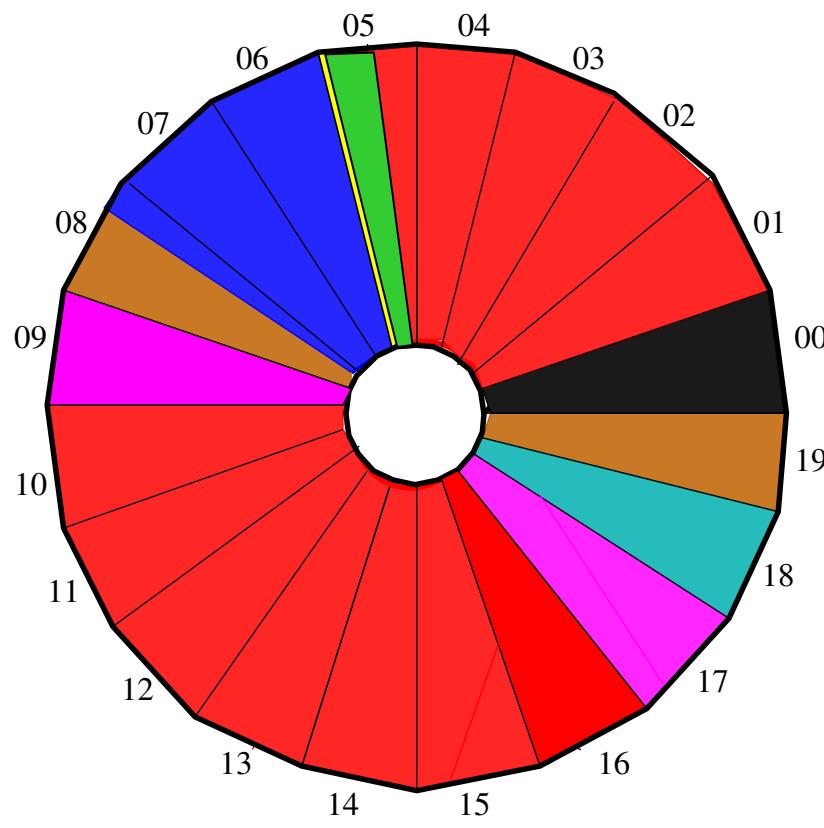
Calorimeter:
1940 plastic scintillators
coupled to low radioactivity PMTs

Magnetic field: 25 Gauss
Gamma shield: Pure Iron ($d = 18 \text{ cm}$)
Neutron shield: 30 cm water (ext. wall)
40 cm wood (top and bottom)
(since march 2004: water + boron)



Particle ID: e⁻, e⁺, γ and α

$\beta\beta$ decay isotopes in NEMO-3 detector



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$\beta\beta0\nu$ search

NEMO-3 Neutrino08

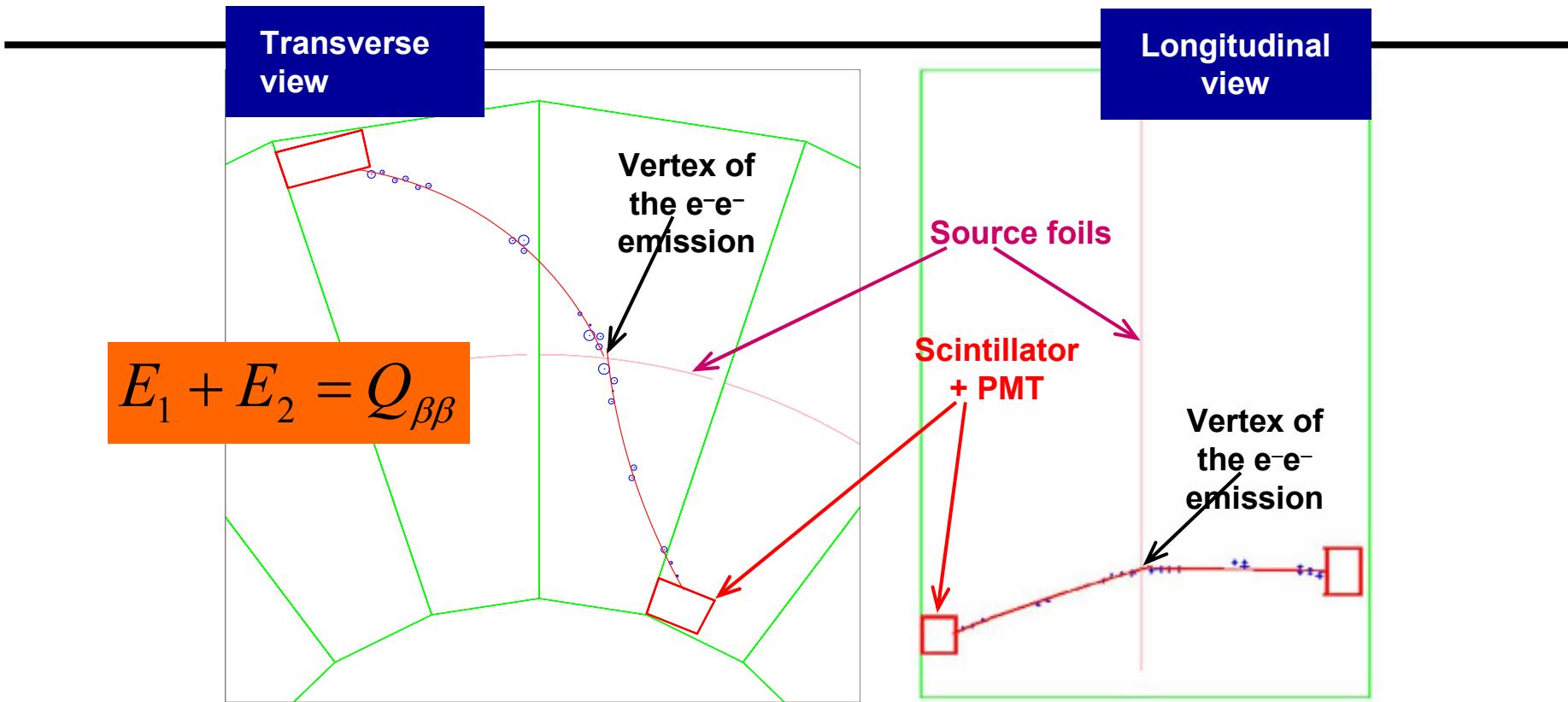
$\beta\beta2\nu$ measurement

^{116}Cd	405 g
$Q_{\beta\beta} = 2805 \text{ keV}$	
^{96}Zr	9.4 g
$Q_{\beta\beta} = 3350 \text{ keV}$	
^{150}Nd	37.0 g
$Q_{\beta\beta} = 3367 \text{ keV}$	
^{48}Ca	7.0 g
$Q_{\beta\beta} = 4272 \text{ keV}$	
^{130}Te	454 g
$Q_{\beta\beta} = 2529 \text{ keV}$	
$^{\text{nat}}\text{Te}$	491 g
Cu	621 g

External bkg
measurement

(Enriched isotopes produced by
centrifugation in Russia)

Event reconstruction



Observables of the final state

- Trajectories of the 2 electrons
- Energies of the 2 electrons
- Time of flight
- Curvature of the tracks in a B-field (+ or -).

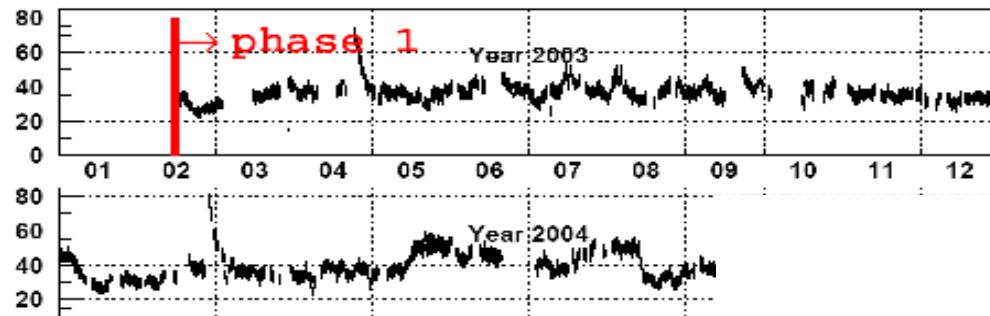
Radon trapping facility

(First developed for SuperKamiokande)

Phase I : February 2003 – September 2004 (radon background in data)

~ 1 $\nu\beta\beta$ -like event/y/kg with $2.8 < E_1 + E_2 < 3.2$ MeV

Phase II : since October 2004 (radon level reduced by a factor of 6)



1 ton of charcoal @ -50°C , 9 bars
air flux = $150 \text{ m}^3/\text{h}$
Input: A(^{222}Rn) $15 \text{ Bq}/\text{m}^3$

Output: A(^{222}Rn) $< 15 \text{ mBq}/\text{m}^3$!!!
reduction factor of 1000



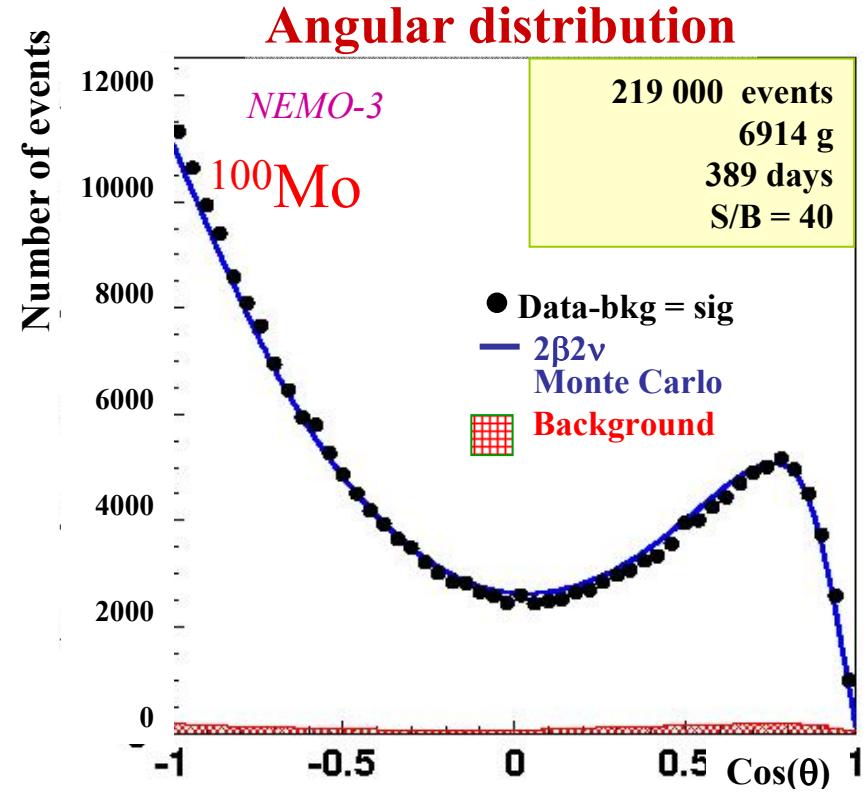
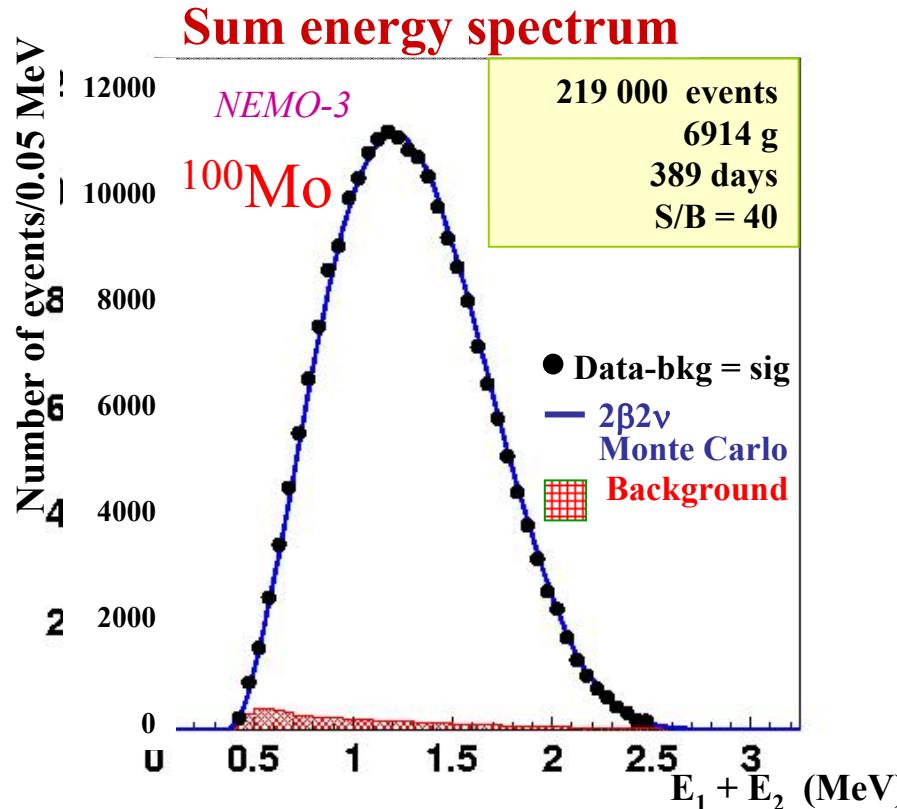
Inside the NEMO 3 tent: factor of 100 – 300

Inside NEMO 3: almost factor of 10 A(^{222}Rn) $\approx 6 \text{ mBq}/\text{m}^3$

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NEMO-3 Neutrino

^{100}Mo $2\nu\beta\beta$ results



$$T_{1/2}(2\nu\beta\beta) = 7.11 \pm 0.02 \text{ (stat)} \pm 0.54 \text{ (syst)} \times 10^{18} \text{ years}$$

Phase 1: Feb. 2003 – Dec. 2004
“High Radon”

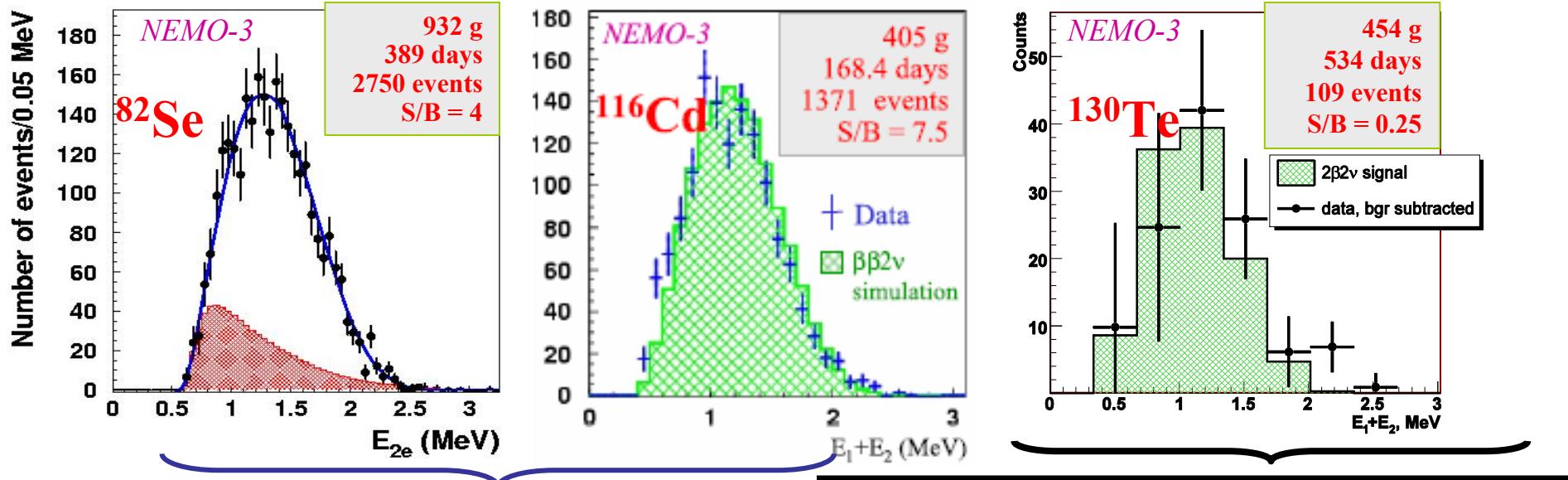
Phys. Rev. Lett. 95 182302 (2005)

28 May 2008

NEMO-3 Neutrino08

Now have in excess of
0.5M events and will
update later this year.

$2\nu\beta\beta$ results with other nuclei



Results for Phase I data. Additional statistics are being analysed and to be published soon.

^{82}Se :

$$T_{1/2} = [9.6 \pm 0.3 \text{ (stat)} \pm 1.0 \text{ (syst)}] \times 10^{19} \text{ y}$$

^{116}Cd :

$$T_{1/2} = [2.8 \pm 0.1 \text{ (stat)} \pm 0.3 \text{ (syst)}] \times 10^{19} \text{ y}$$

Preliminary:
Result for Phase 1 and 2 data.

^{130}Te :

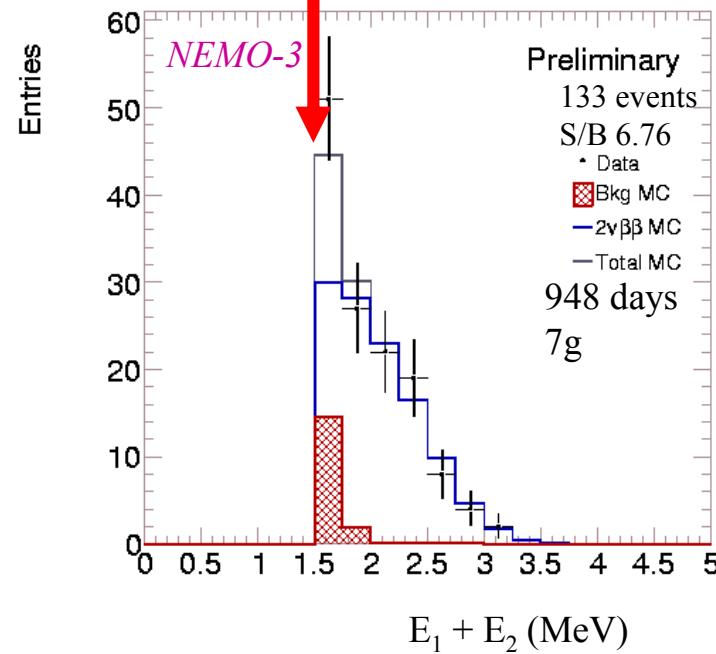
$$T_{1/2} = [7.6 \pm 1.5 \text{ (stat)} \pm 0.8 \text{ (syst)}] \times 10^{20} \text{ y}$$

$2\nu\beta\beta$ is important:

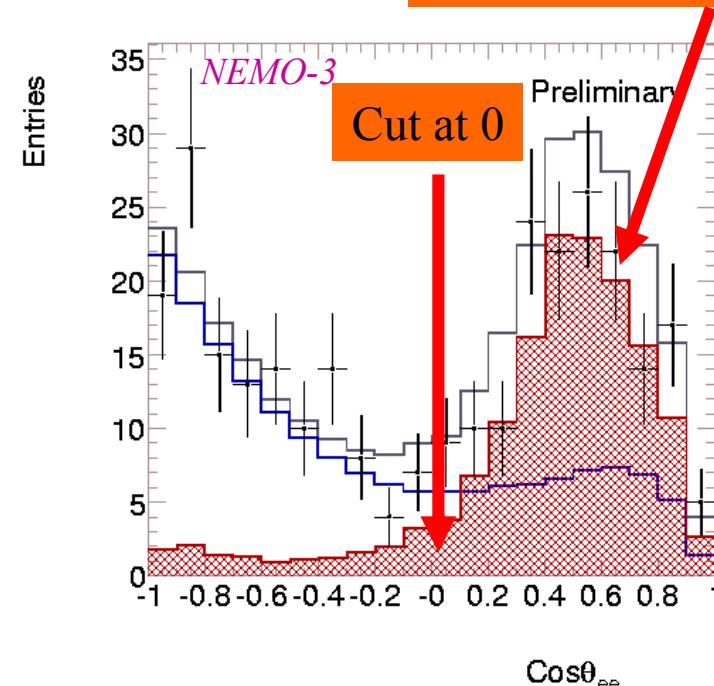
- 1) Experimental input to NME calculation
- 2) Ultimate background for $0\nu\beta\beta$

New result: ^{48}Ca $\beta\beta$

Cut at 1.5 MeV



High bkgs here due to contamination with ^{90}Sr .

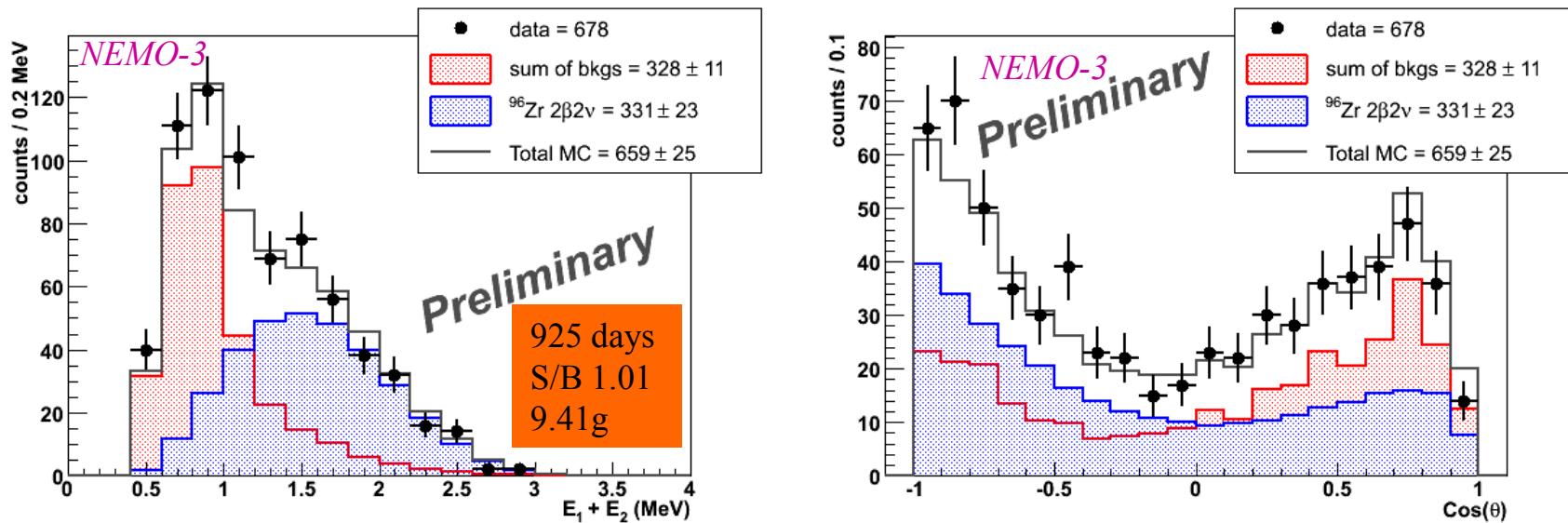


Preliminary results: $T_{1/2} (2\nu\beta\beta) = [4.4 ^{+0.5}_{-0.4} (\text{stat}) \pm 0.4 (\text{syst})] \times 10^{19} \text{ y}$

$T_{1/2} (0\nu\beta\beta) > 1.3 \times 10^{22} \text{ y (90\% C.L.)} \rightarrow \langle m_\nu \rangle < 29.6 \text{ eV (90\% CL), Eff. 22\%}$

Refs: E Caurier et al., Phys. Rev. Lett. 100 (2008) 052503 (NME)

New result: ^{96}Zr $2\nu\beta\beta$



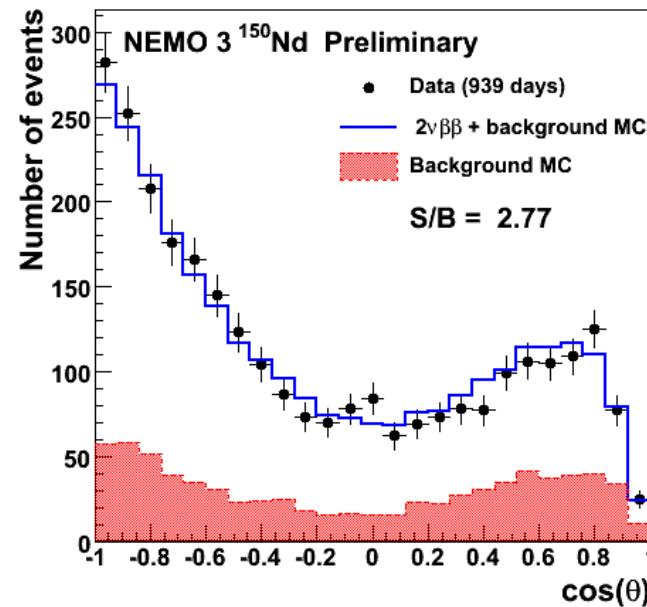
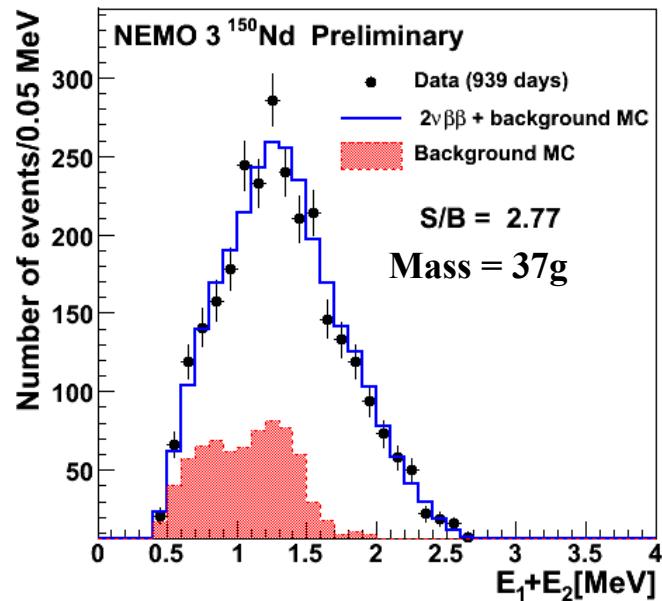
Preliminary result:

$$^{96}\text{Zr}: \quad T_{1/2}(2\nu\beta\beta) = [2.3 \pm 0.2(\text{stat}) \pm 0.3(\text{syst})] \times 10^{19} \text{ y}$$

$T_{1/2}(0\nu\beta\beta) = 8.6 \times 10^{21} \text{ y (90\% C.L.)} \rightarrow \langle m_\nu \rangle < 7.4 - 20.1 \text{ eV (90\% CL), Eff. 19\%}$

Refs for NME : Simkovic, et al., Phys. Rev. C 77 (2008) 045503
 Kortelainen and Suhonen, Phys. Rev. C 76 (2007) 024315

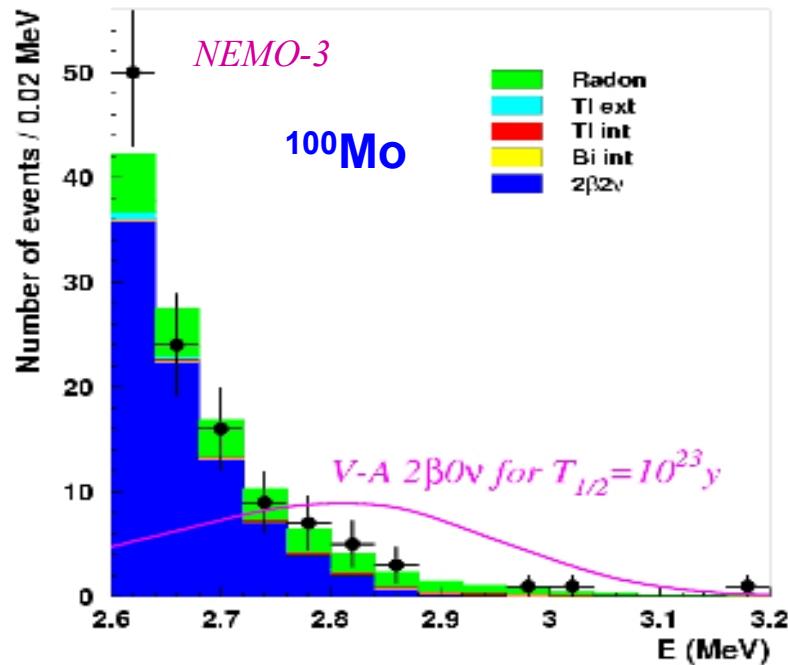
Recent result: ^{150}Nd $2\nu\beta\beta$ (Moriond)



Preliminary results: $T_{1/2} (2\nu\beta\beta) = [9.20 ^{+0.25}_{-0.22} (\text{stat}) \pm 0.62 (\text{syst})] \times 10^{18} \text{ y}$
 Expected $T_{1/2} (0\nu\beta\beta) = 1.45 \times 10^{22} \text{ y}$
 Observed $T_{1/2} (0\nu\beta\beta) = 1.8 \times 10^{22} \text{ y}$ (90% C.L.) Eff. 19%
 $\langle m_\nu \rangle < 1.7 - 2.4 \text{ eV}$ (90% CL), QRPA (2007, corrected paper compared to 2006)
 deformation not taken into account
 $\langle m_\nu \rangle < 4.8-7.6 \text{ eV}$: pseudo-SU(3) Hirsh (95) deformation taken into account
 Ref for NME : V. Rodin et al., Nucl. Phys. A 793 (2007) 213.
 J.H. Hirsch et al., Nucl. Phys. A 582 (1995) 124.

$0\nu\beta\beta$ of ^{100}Mo and ^{82}Se (To be updated)

693 days of data
Phase I + Phase II

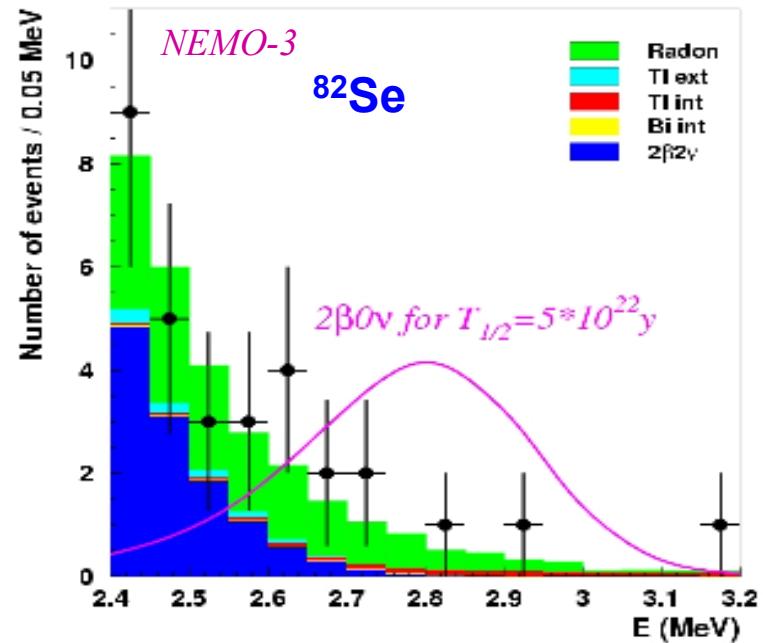


$T_{1/2} > 5.8 \times 10^{23} \text{ y } @ 90\% \text{ C.L.}$

$\langle m_\nu \rangle < (0.8 - 1.3) \text{ eV [1-3]}$

Data until spring 2006

693 days of data
Phase I + Phase II



$T_{1/2} > 2.1 \times 10^{23} \text{ y } @ 90\% \text{ C.L.}$

$\langle m_\nu \rangle < (1.4 - 2.2) \text{ eV [1-3]}$

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NEM

NME:

- [1] M.Kortelainen and J.Suhonen, Phys.Rev. C 75 (2007) 051303(R).
- [2] M.Kortelainen and J.Suhonen, Phys.Rev. C 76 (2007) 024315.
- [3] V.A.Rodin et al., Nucl.Phys. A 793 (2007) 213.

From NEMO-3 to SuperNEMO

$$T_{1/2}(\beta\beta 0\nu) > \ln 2 \times \frac{\mathcal{N}_A}{A} \times \frac{M \times \epsilon \times T_{obs}}{N_{90}}$$

NEMO-3		SuperNEMO
^{100}Mo	isotope	^{82}Se - baseline (^{150}Nd if it can be enriched)
7 kg	isotope mass M	100-200 kg
18 %	efficiency ϵ	$\sim 30 \%$
$^{208}\text{Tl}: < 20 \mu\text{Bq/kg}$ $^{214}\text{Bi}: < 300 \mu\text{Bq/kg}$	internal contaminations ^{208}Tl and ^{214}Bi in the $\beta\beta$ foil	$^{208}\text{Tl} \leq 2 \mu\text{Bq/kg}$ if ^{82}Se : $^{214}\text{Bi} \leq 10 \mu\text{Bq/kg}$
8% @ 3MeV	energy resolution (FWHM)	4% @ 3 MeV
$T_{1/2}(0\nu\beta\beta) > 2 \times 10^{24} \text{ y}$ $\langle m_\nu \rangle < 0.3 - 0.9 \text{ eV}$		$T_{1/2}(0\nu\beta\beta) > 10^{26} \text{ y}$ $\langle m_\nu \rangle < 0.04 - 0.11 \text{ eV}$

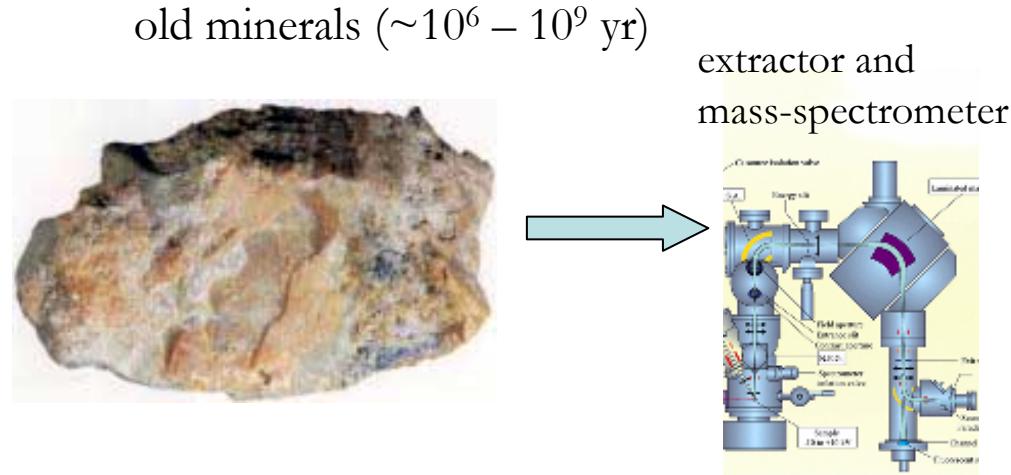
See SuperNEMO poster

Summary

- NEMO's Tracking + Calorimetry approach is unique
 - Good rejection of backgrounds
 - Choice of isotopes
 - Reconstruction of kinematics
- NEMO3 is taking data
 - $2\nu\beta\beta$ factory: precise life-time measurements for 7 isotopes (out of 9 main candidates).
 - New results for ^{48}Ca and ^{96}Zr .
 - Data taking until end 2010: 340-590 meV.
- SuperNEMO: 3 year Design Study addresses most critical issue
 - Based on design study results full proposal for 100+ kg detector in 2009.
 - ^{82}Se – baseline, ^{150}Nd possible.
 - First module 2010/11.
 - All 20 modules ~2013.
- Target sensitivity: 50-100 meV by 2016

Backup slides

How constant are coupling constants? $\beta\beta$ is sensitive to G_f variations ($\sim G_f^4$)



$\beta\beta$ decay was first detected in geochemical experiments ($^{130}\text{Te} \rightarrow ^{130}\text{Xe}$)

Daughter isotope (^{130}Xe) extracted from an old mineral and number of atoms counted

^{130}Te geochemical measurements:

$(25 \pm 2) \times 10^{20}$ yrs (Kirsten 83)

$(27 \pm 2) \times 10^{20}$ yrs (Bernatowicz 93)

$(8 \pm 1) \times 10^{20}$ yrs (Manuel 91, Takaoka 96)

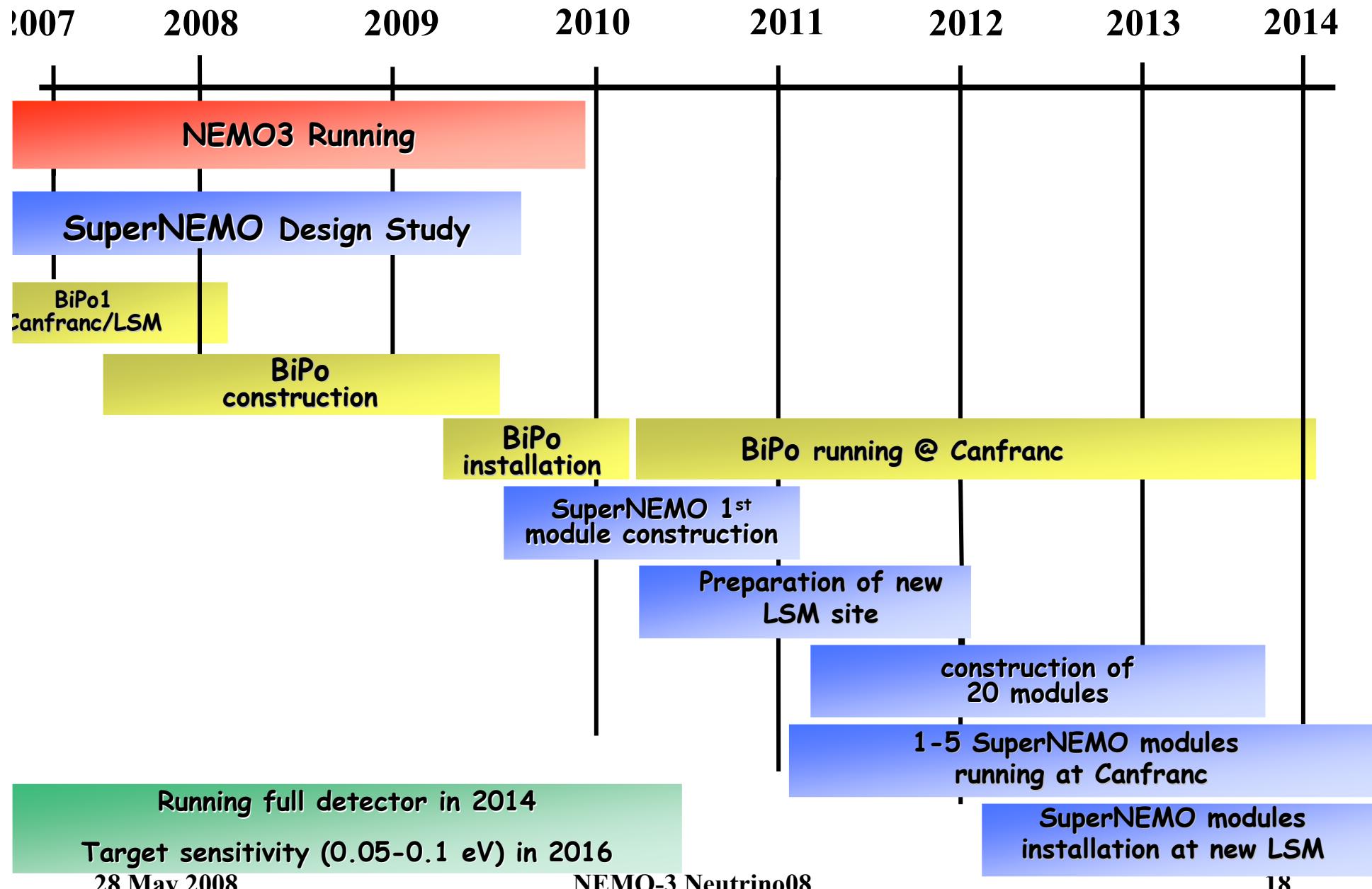
“old” samples ($\sim 10^9$ yrs)

“new” samples (few $\times 10^6$ yrs)

NEMO3 result (“present” $\beta\beta$ rate): $(7.6 \pm 1.7) \times 10^{20}$ yrs

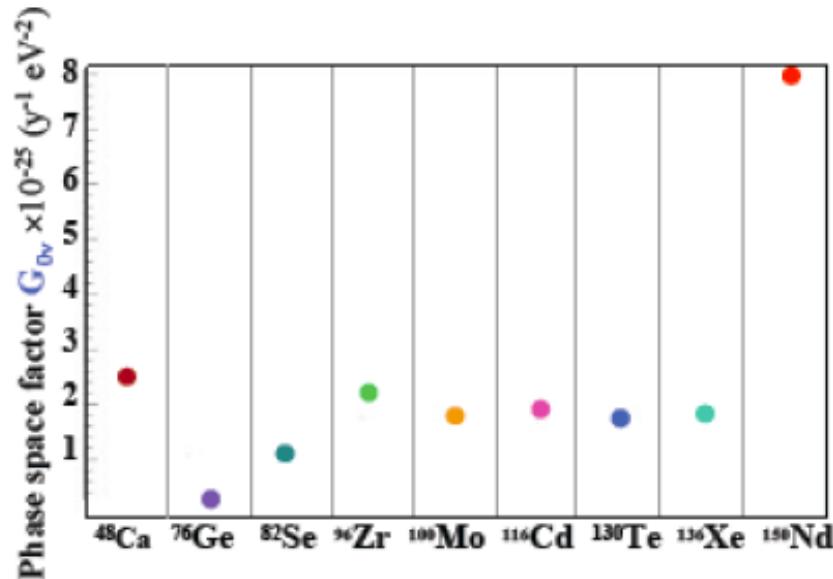
Difference between $\beta\beta$ rates in past and present due to time dependence of Fermi constant???

Suggestion: Carry out geochemical isotope analyses with $^{100}\text{Mo} \rightarrow ^{100}\text{Ru}$, $^{96}\text{Zr} \rightarrow ^{96}\text{Mo}$ (daughter not gas) etc and compare with direct measurements (precise NEMO3 results available).



Choice of Isotope

$$\frac{1}{T_{0\nu}} = G_{0\nu} M_{0\nu}^2 \langle m_\nu \rangle^2$$



Purification of 4kg of ^{82}Se underway
(INL, US).

Enrichment of ^{150}Nd possible.

Criteria of choice:

- High Q_{bb} value
- Phase space $G_{0\nu}$
- 2nbb half-life
- natural abundance
- enrichment possibilities.

Two main options:

	^{150}Nd	^{82}Se
$Q_{\beta\beta}$ (MeV)	3.367	2.995
$G_{0\nu}$ ($y^{-1} eV^{-2}$)	8×10^{-25}	10^{-25}

^{82}Se obtained by centrifugation.
Impossible for ^{150}Nd , only laser enrichment.

$\beta\beta$ decay is about background suppression

Natural radioactivity:

$$T_{1/2}(^{238}\text{U}, ^{232}\text{Th}) \sim 10^{10} \text{ yr}$$

$$T_{1/2}(0\nu\beta\beta) > 10^{25} \text{ yr}$$

^{238}U and ^{232}Th produce ^{214}Bi ($Q_\beta = 3.27 \text{ MeV}$) and ^{208}Tl ($Q_\beta = 4.99 \text{ MeV}$)

Radon!

Cosmogenic activity

Underground is a must

Due to tracking, for SuperNEMO the main focus is on source (foil) purity.

Must be super-duper-ultra low $< 10 \mu\text{Bq/kg}$! (For reference humans 10-100 Bq/kg
typical materials $\sim 1\text{Bq/kg}$)

But how to measure these levels?!

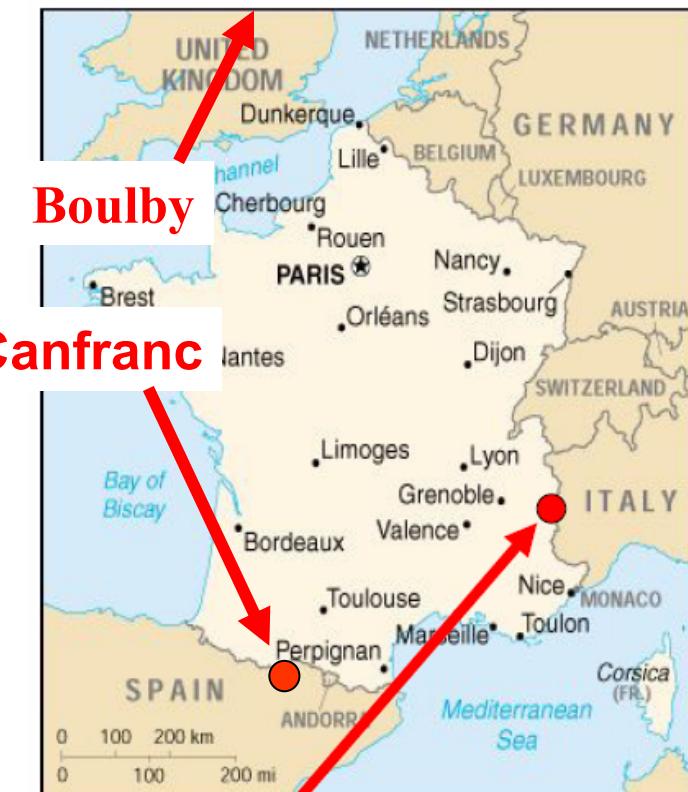
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20

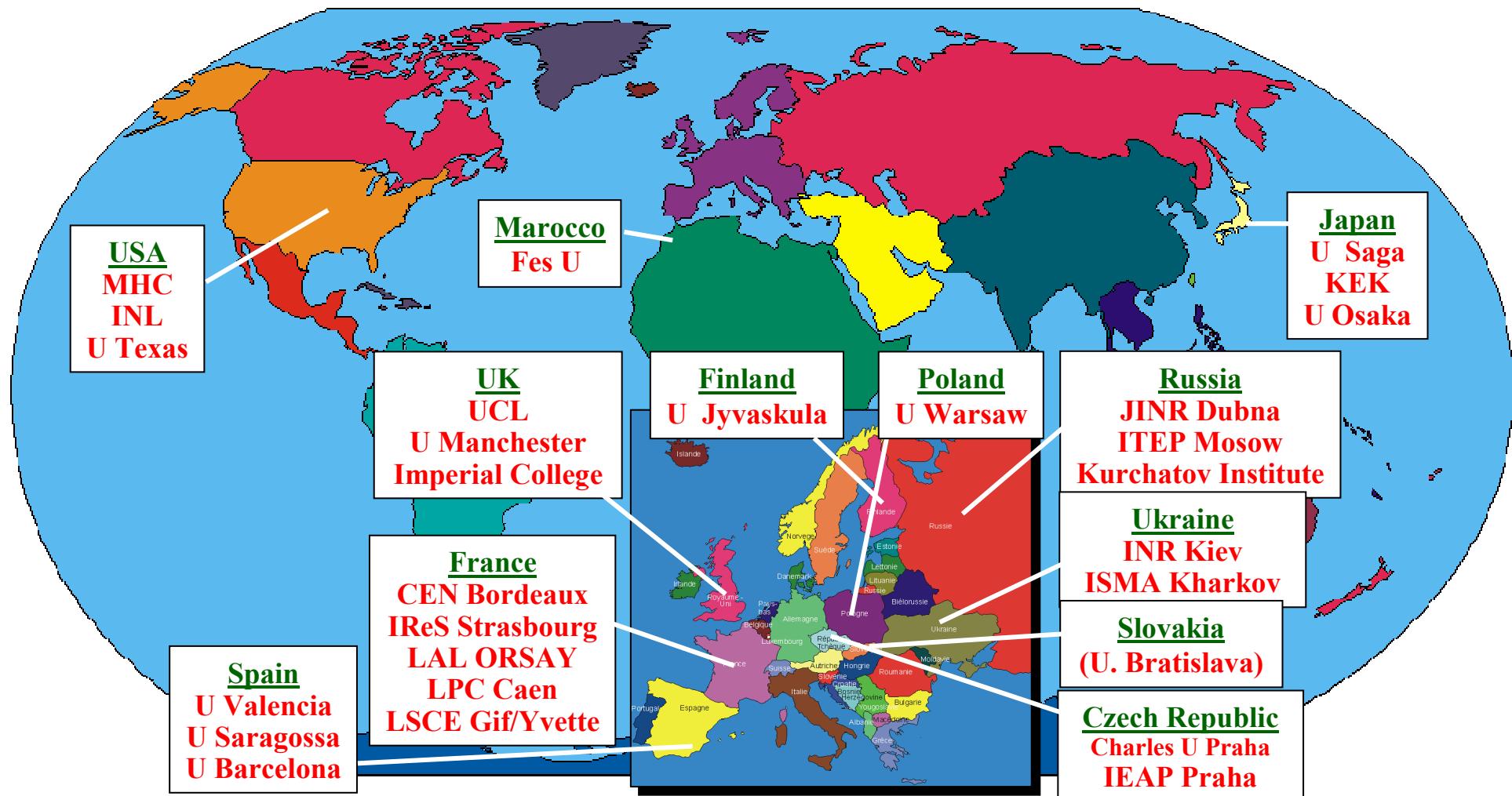
Choice of site

- Canfranc
 - 2500 m.w.e
- LS Modane
 - 4800 m.w.e
- Boulby
 - 2800 m.w.e



LS Modane, FR
Tunnel Frejus

~ 90 physicists, 12 countries, 27 laboratories



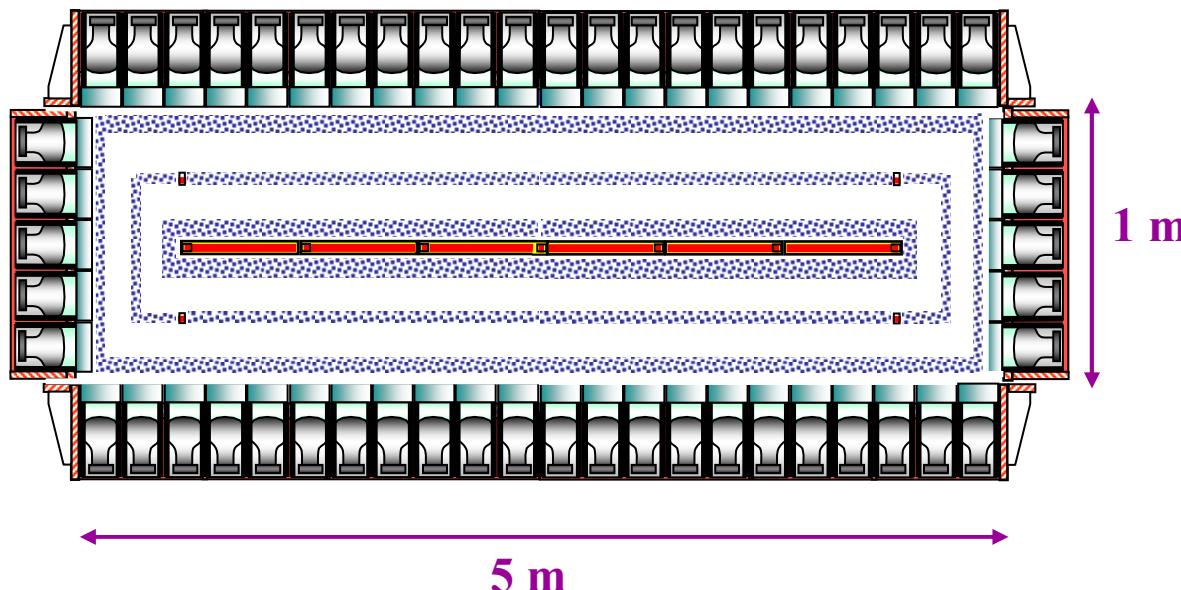
Planar geometry. 20 modules for 100+ kg

Single model (baseline design)

Source (40 mg/cm²) 12m², tracking volume (~2-3k Geiger channels). calorimeter (0.5-1k ch)

Total:

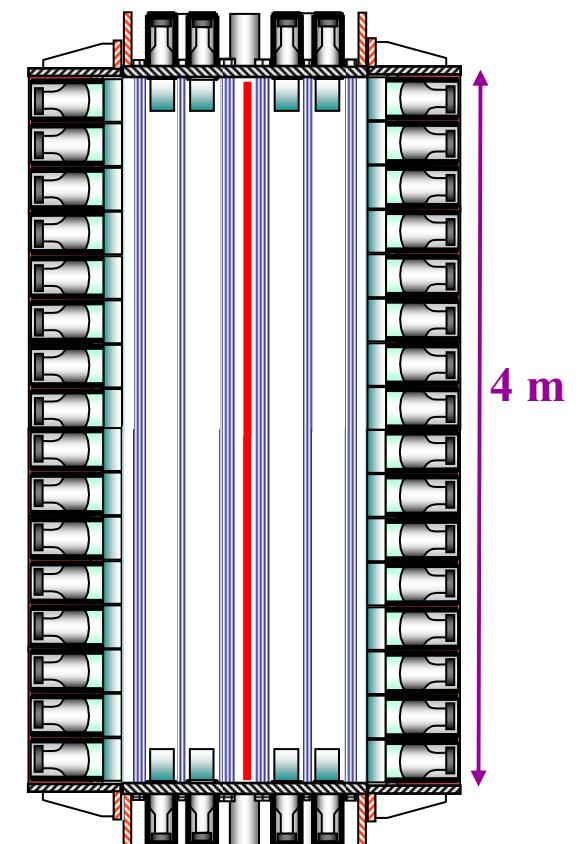
- ~ 40-60k geiger channels for tracking
- ~ 10-20k PMTs (3k if scintillator bars design)



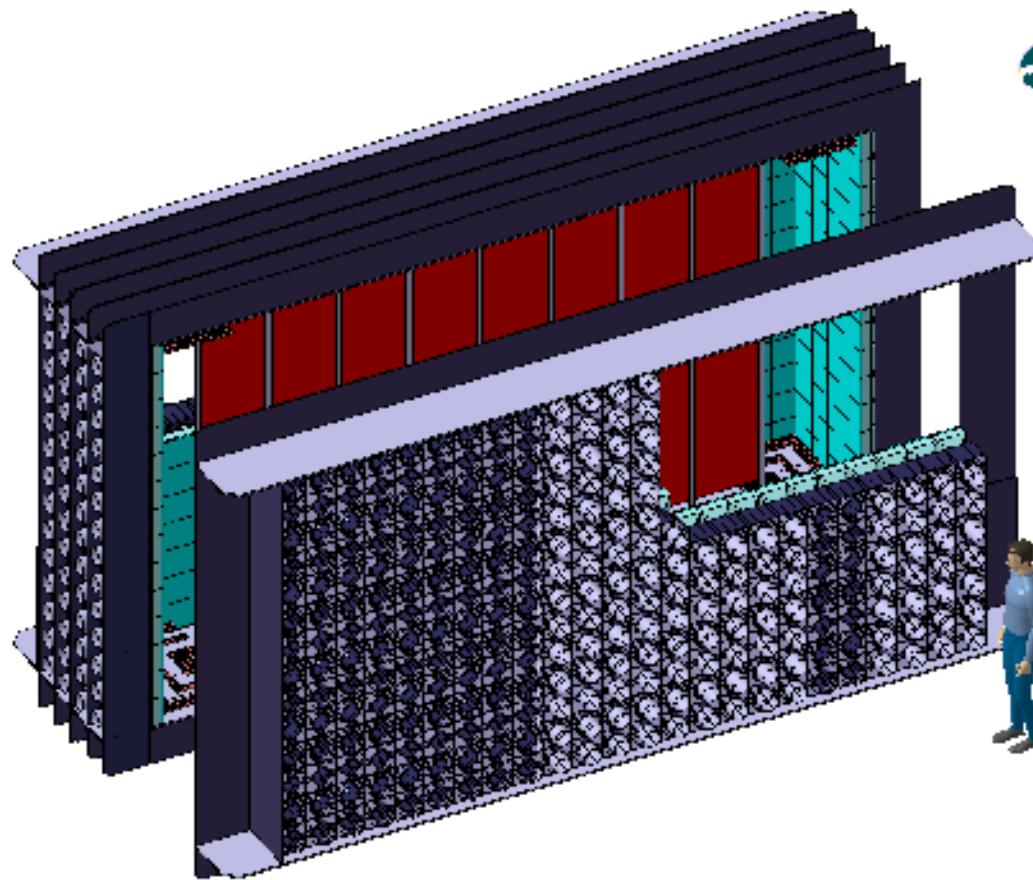
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Top view

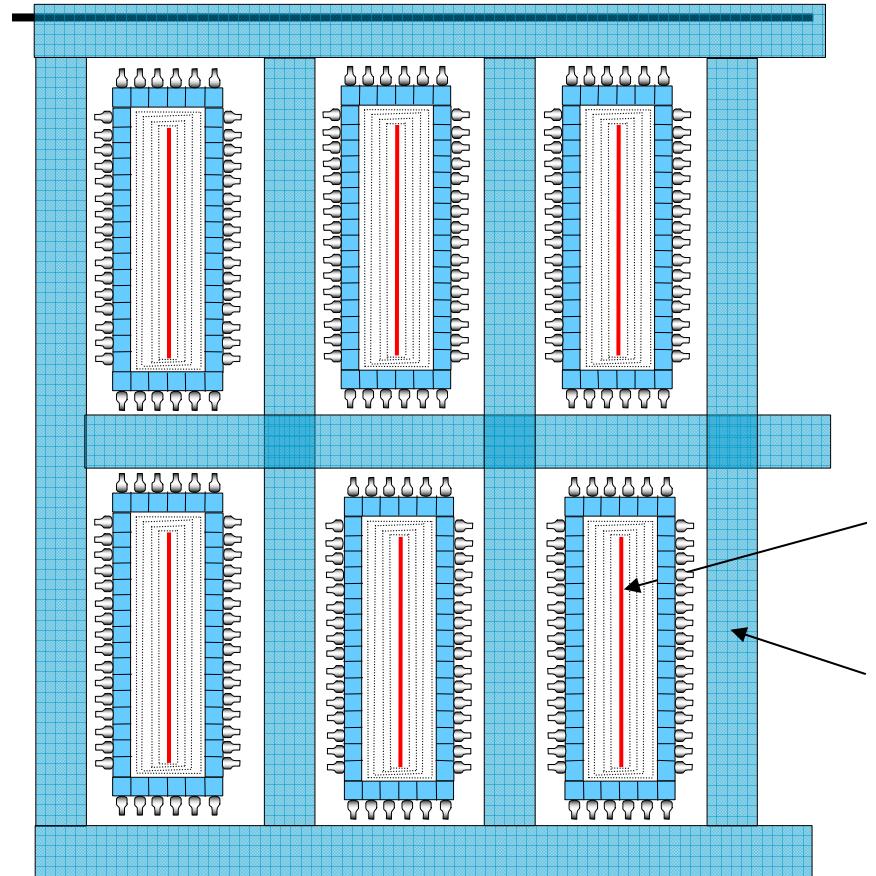
NEMO-3 Neutrino08



Side view 23



Single sub-module
with ~5-7 kg of isotope



~20 sub-modules for 100+ kg of isotope
surrounded by water shielding